lignite marginal and inferred marginal reserves.—Tonnage estimates for these classes of coal reserves are determined by summing the marginally recoverable quantities of coal in the reserve base and inferred reserve base and are assignable to the same categories of thicknesses of coal and overburden described for lignite reserves; coal may be divided into the lignite A and B groups. *Lignite marginal and inferred marginal reserves* must be considered as uncertain as to their economic producibility at the time of classification. Facilities for extraction need not be in place and operative.

lignite inferred reserves.—Tonnage estimates for this class of reserves are determined by summing the recoverable quantities of coal in the inferred reserve base and are assignable to the same categories of thicknesses of coal and overburden described for lignite reserves. Also, this class of coal may be divided into the lignite A and B groups. Such inferred reserves must be considered economically producible at the time of classification; facilities for extraction need not be in place and operative.

lignite reserve base and inferred reserve base.—See ***reserve base*** for thickness of coal and thickness of overburden criteria.

lignite resources.—Tonnage estimates for this class of coal are determined by summing the estimates for lignite identified and undiscovered resources. The same thickness categories as for lignite reserves are to be used with the addition of a 30–60 inches (75–150 cm) category (see specific instruction No. 3, p. 34), and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). The tonnage estimates for this class of coal may be divided into lignite A and B groups.

measured.—Accessed and virgin coal that lies within a radius of 1/4 mile (0.4 km) of a point of thickness of coal measurement. (See fig. 4.)

measured marginal reserves.—Accessed and virgin coal that lies within a radius of 1/4 mile (0.4 km) of a point of thickness of coal measurement. Tonnage estimates for this category of reserves includes those parts of a measured reserve base that at the time of determination border on economic producibility assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic producibility should be documented. (See **measured**, p. 12; and fig. 4.)

measured reserves.—*Measured reserves* are estimated from a measured reserve base by subtracting the sum of the assumed tonnage of coal that will be lost-in-mining and measured marginal reserves. The remaining tonnage—the coal that is assumed will be extracted—is *measured reserves* which must be considered as economically producible at the time of classification; however, facilities for extraction need not be in place and operative.

measured reserve base.—A *measured reserve base* is determined by projection of thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic evidence for a radius of 1/4 mile (0.4 km). A *measured reserve base* includes anthracite and bituminous coal 28 inches (70 cm) or more thick and subbituminous coal 60 inches (150 cm) or more thick to depths of 1,000 feet (300 m) and lignite 60 inches (150 cm) or more thick to depths of 500 feet (50 m).

measured resources.—Tonnage estimates for *measured resources* are computed by projection of thicknesses of coal and overburden, rank, and quality data for a radius of 1/4 mile (0.4 km) from a point of measurement. Measured resources include anthracite and bituminous coal 14 inches (35 cm) or more thick and lignite and subbituminous coal 30 inches (75 cm) or more thick to depths of 6,000 feet (1,800 m). The quantity of coal estimated as measured is the same as the sum of the measured reserve base and measured subeconomic resource.

original resources.—Tonnage estimates determined for coal in the ground prior to production. Where coal has been mined, estimates are made by summing remaining resources, cummulative production, and coal lost-in-mining. An estimate of total original resources is the sum of the original resources determined for many mines, fields, basins, regions, provinces, States, and the Nation. (See ***resources*** for thicknesses of coal and overburden; and **lost-in-mining**, p. 12.)

other occurrences, noneconomic coal.—Such coal, except where mined locally, consists of anthracite and bituminous coal beds less than 14 inches (35 cm) thick; lignite and subbituminous coal beds less than 30 inches (75 cm) thick; and all coal beds that are buried by more than 6,000 feet (1,800 m) of overburden; coal containing more than 33 percent ash; and that coal lost-in-mining that is considered noneconomic. Tonnage estimates are optional for such coal. However, if estimates are made, they should be reported as "other occurrences" and not

as resources. However, where currently mined, coal that is considered too thin or too high in ash and would normally be classed as "other occurrences" is to be classed as reserves.

rank assignments.—The assignment of rank is a necessary part of classifying a coal; however, data for determining rank are commonly sparse or are far-removed from the localities where the data required for rank assignment is needed. In general, rank gradually changes laterally over many miles or stratigraphically over hundreds to thousands of feet. Because of the lack of data in some areas, conclusions concerning *rank assignments* commonly must be derived from analytic or petrographic determinations made on coal that lies some distance from where the rank assignment is desired. Conclusions concerning rank where analytic or petrographic data are sparse must be viewed as tentative. However, if a geologist's understanding of the setting of the area sampled is adequate, the rank assignment probably will be correct even though the rank data are sparse.

rank calculation.—The rank of coal is to be calculated by using the following instructions which are quoted from the standard specifications for classification of coals by rank (ASTM Standards, 1981, p. 212–216):

8. Calculation to Mineral-Matter-Free Basis

8.1 *Calculation of Fixed Carbon and Calorific Value:* For classification of coal according to rank, fixed carbon and calorific value shall be calculated to the mineral-matter-free basis in accordance with either the Parr formulas, Eqs 1, 2, and 3, or the approximation formulas, Eqs 4, 5, and 6, that follow. In case of litigation use the appropriate Parr Formula.

8.2 Calculation to Mm-free basis:

Parr Formulas:

$$\text{Dry, Mm-free FC} = \frac{(\text{FC} - 0.15\text{S})}{[100 - (\text{M} + 1.08\text{A} + 0.55\text{S})]} \times 100 \quad (1)$$

$$\text{Dry, Mm-free VM} = 100 - \text{Dry, Mm-free FC} \quad (2)$$

$$\text{Moist, Mm-free Btu} = \frac{(\text{Btu} - 50\text{S})}{[100 - (1.08\text{A} + 0.55\text{S})]} \times 100 \quad (3)$$

Note—The above formula for fixed carbon is derived from the Parr formula for volatile matter.

Approximation Formulas:

$$\text{Dry, Mm-free FC} = \frac{\text{FC}}{[100 - (\text{M} + 1.1\text{A} + 0.1\text{S}]} \times 100 \quad (4)$$

$$\text{Dry, Mm-free VM} = 100 - \text{Dry, Mm-free FC} \quad (5)$$

$$\text{Moist, Mm-free Btu} = \frac{\text{Btu}}{[100 - (1.1\text{A} + 0.1\text{S})]} \times 100 \quad (6)$$

where

Mm = Mineral matter,
Btu = British thermal units per pound (calorific value),
FC = percentage of fixed carbon,
VM = percentage of volatile matter,
M = percentage of moisture,
A = percentage of ash, and
S = percentage of sulfur.

Above quantities are all on the inherent moisture basis. This basis refers to coal containing its natural inherent or bed moisture but not including water adhering to the surface of the coal.

recovery factor method.—Only a part of the coal in any deposit can be extracted when mined. The coal not extracted during underground mining, strip mining, or auger mining; the coal that becomes a part of a underground or strip-mine waste pile; or the coal that is not removed adjacent to a strip-mine or underground-mine boundary is considered as lost-in-mining unless sufficient tonnages are left unextracted so that additional mining or recovery can be foreseen.

If it is not feasible or possible to calculate the reserves of an area using an economic analysis, a reasonable approximation of the reserves can be determined by using the *recovery factor method* described hereafter.

Each operating mine has a unique percentage of coal that is recovered. This percentage is termed the recovery factor of the mine and is obtained from the following formula:

$$RF = \frac{Y \times 100}{X}$$

where

RF = Recovery factor or percent coal estimated extractable during mining,
X = The total tonnage of coal estimated in the ground,
Y = The tonnage of coal estimated to be recoverable during mining.

A recovery factor can be applied to a reserve base to obtain an estimate of the reserves of an area. Such use of a recovery factor is appropriate when there is a paucity of geologic data for estimating the tonnage of potentially extractable coal.

It is difficult to estimate accurately the recoverable coal in a very large area such as a field, region, province, basin, State, or the Nation because it is impossible to determine how much coal in the area will not be mined for legal or environmental reasons, what method

or methods of mining will be used, and what the average recovery factor will be for all mining methods.

A reserve base and reserves have been estimated by industry for most operating mines in the United States. Generally, data that can be used to compute recovery factors for individual mines are closely held by the operators; therefore, there is little publicly available information to guide estimators in determining local, regional, and national recovery factors. Commonly, estimators must extrapolate recovery factors from experience gained in a few mines by assuming that (1) geologic conditions controlling mining will be similar, and (2) success in the recovery of coal in unmined areas will be similar to that of mined areas utilizing the same mining method. Such extrapolation of recovery factors from a few well known mined areas to less well known or unknown areas requires experience regarding the geology, the mining method or methods to be employed, and an awareness of the difficulties, geologic and otherwise, that affect the estimation of reserves. Area, quadrangle, township, field, basin, province, county, State, and national recovery factors can be determined by using formulas after determining the mean recovery factor in percent for many mines, ascertaining the quantity of reserve base coal in the area of study, and ascertaining the total quantity of coal that is restricted from mining for any legal, environmental or technologic reason. These formulas are:

$$Z = 100\,\frac{X}{Y}$$

$$NRF = W(100 - Z)$$

where

X = tonnage of coal restricted from extraction for any legal, environmental, or technologic reason,

Y = tonnage of coal included in the reserve base category of a large area,

Z = restricted coal (percent),

W = recovery factor percent obtained from local mines, and

NRF = National, State, or large area recovery factor in percent applied to all coal including restricted.

In the United States, recovery factors for underground mining as determined from mine maps of abandoned and operating mines generally range from about 35 to about 70 percent and average about 50 percent. Similarly, recovery factors for abandoned and operating surface mines range from about 70 to 95 percent and average about 80 percent. These local recovery factors are valid for individual mines but are not valid for large areas because they fail to consider the coal lost-in-mining such as (1) the coal that will not be mined between properties, and (2) coal in overlying and underlying beds rendered usuitable for future mining by past underground mining. Further, the local recovery factors do not consider the coal that is restricted or prohibited from mining, such as the coal underlying national parks and wild life sanctuaries; coal that is too deep and too thin to be mined because of excessive costs; and coal that cannot be mined because of unsolved technologic, geologic, or engineering problems.

The authors recommend applying a recovery factor of 50 percent to the reserve base when computing underground and surface mining reserves of large areas. However, if actual local recovery factors have been calculated, the procedure outlined with the two formulas should be implemented for smaller areas.

remaining resources.—The resources remaining in the ground after prior mining. These resources include identified and undiscovered resources and include coal lost-in-mining whose attributes indicate possible future recovery. See ***resources***, for thickness of coal and overburden criteria, and figure 3.

reserve base.—A tonnage estimate for this category of coal consists of the sum of the estimates for measured and indicated reserves, marginal reserves, and a part of the measured and indicated subeconomic resources (the coal that has or will be lost-in-mining). The *reserve base* is the same as the demonstrated reserve base. The term *reserve base* is preferred for reports of the U.S. Geological Survey. The criteria for the *reserve base* include bituminous coal and anthracite 28 inches (70 cm) or more thick, subbituminous coal 5 feet (1.5 m) or more thick that occurs at depths to 1,000 feet (300 m), and lignite 5 feet (1.5 m) or more thick that occurs at depths to 500 feet (150 m).

Discussion: Individual reserve bases, where needed and appropriate, are to be determined by categories of reliability, thicknesses of coal and overburden; rank, chemical constituents, ash content, heat value, and potential usage. Additionally, estimated individual reserve base estimates are to be summed into totals for each township, quadrangle, coal field, basin, region, province, township and range, county, State, and the Nation. Assignment of coal to a reserve

base is controlled by physical and chemical criteria such as categories of reliability, thicknesses of coal and overburden, rank of coal, and knowledge of depositional patterns of coal beds and associated structural features. Changing economic, technologic, and environmental considerations do not control assignment of coal to a reserve base. In contrast, the discrimination of reserves is largely controlled by economic factors such as judgments of cost, profit, and supply of and demand for coal. Reserve discrimination is controlled secondarily by advances or differences in mining, preparation and transportation technologies, and by environmental regulations, laws, and judicial rulings.

The physical and chemical criteria used to assign coal to a reserve base category have been used already to evaluate many coal beds that are currently mined in the United States. These evaluations indicate coal assigned to a reserve that is derived from a physically-chemically defined *reserve base* can be expected to be economically minable with a high degree of confidence. In a few places, however, where the thickness of a coal bed or associated rock conditions are exceptionally variable or severe, the varying tonnages of coal classified as a reserve from a physically and chemically defined *reserve base* may or may not prove to be extractable at a profit.

Changes in environmental laws and regulations generally affect the tonnages of coal assigned to the various categories of the *reserve base*; however, assessments of these changes have not been made.

reserves.—Reserve tonnage estimates are to be determined by summing the recoverable quantities of coal in the reserve base for each rank of coal and are assigned to the following categories: (1) thickness of overburden—0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 m to 300 m); and (2) thickness of coal—28 to 42 inches (70 to 105 cm), 42 to 84 inches (105 to 215 cm), 84 to 168 inches (215 to 430 cm), and more than 168 inches (>430 cm) for anthracite and bituminous coal; and 5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (>12.0 m) for subbituminous coal and lignite. (See specific instruction No. 3, p. 34.) *Reserves* must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative. In addition, categories based on potential mining methods (surface and underground); chemical constituents such as sulfur, phosphorous and ash content; heat value; and usage such as metallurgical, steam, petrochemical, gasification, and liquefaction are desirable. *Reserves* and marginal reserves are estimated by determining the amount of coal in each reserve base category that can be extracted at the time of classification (*reserves*), and the amount that borders on being extractable at a profit (marginal reserves). These two amounts and the amount that will be lost-in-mining, when summed, are equal to the reserve base. The estimates of each reserve category are to be totaled into quadrangle, township, field, basin, region, province, county, and State estimates, and into a national total, and then the various estimates for all categories are to be totaled similarly to reach an inclusive estimate of all *reserves*.

Reserves are derived from the reserve base, which includes bituminous coal and anthracite 28 inches (70 cm) or more thick, subbituminous coal 5 feet (1.5 m) or more thick that occurs at depths to 1,000 feet (300 m), and lignite 5 feet (1.5 m) or more thick that occurs at depths to 500 feet (150 m). *Reserves* also include thinner and (or) more deeply buried beds of these ranks of coal that are currently being mined.

resources.—Tonnage estimates for coal resources are determined by summing the estimates for identified and undiscovered deposits of coal that are 14 inches (35 cm) or more thick for anthracite and bituminous coal and under less than 6,000 feet (1,800 m) of overburden, and 30 inches (75 cm) or more thick for lignite and subbituminous coal and under less than 6,000 feet (1,800 m) of overburden.

speculative resources.—As of publication of this circular, there are no speculative resources of coal estimated for the United States. However, if it is desirable to make such estimates, the definition of Speculative Resources (p. 20) and the criteria for ***resources*** will be followed, and the geologic evidence supporting the estimates and methods of quantification will be made available publicly.

subbituminous coal inferred reserves.—Tonnage estimates for this class of coal are determined by summing the recoverable quantities of coal in the inferred reserve base and are assigned to the same categories of thickness of coal and overburden described for ***subbituminous coal reserves***. This class of coal may be divided into the same rank groups as described for ***subbituminous coal reserves***. Inferred reserves must be considered as economically producible at the time of classification. However,

facilities for extraction need not be in place and operative.

subbituminous coal marginal and inferred marginal reserves.—Tonnage estimates for these classes of coal are determined by summing the marginally recoverable quantities of coal in the reserve base and inferred reserve base, respectively, and are assigned to the same categories of thicknesses of coal and overburden described for ***subbituminous coal reserves***. These classes of coal may be divided into the same rank groups as described for ***subbituminous coal reserves***. Marginal and inferred marginal reserves must be considered uncertain as to their economic producibility at the time of classification. Facilities for extraction need not be in place and operative.

subbituminous coal reserves.—Tonnage estimates for this class of coal are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal—5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (>12.0 m) (see specific instruction No. 3, p. 34); and (b) thickness of overburden—0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m). Such reserve estimates may be divided into subbituminous A, B, and C rank groups. Reserves assigned to this coal class must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative.

subbituminous coal reserve base and inferred reserve base.—See ***reserve base*** for thickness of coal and thickness of overburden categories.

subbituminous coal resources.—Tonnage estimates for this class of coals are determined by summing the estimates for identified and undiscovered subbituminous coal resources. The same thickness categories as for subbituminous coal reserves are to be used with the addition of a 30 inches–5 feet (75 cm–1.5 m) category (see specific instruction No. 3, p. 34), and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). Such resource estimates may be divided into subbituminous coal A, B, and C rank groups.

subeconomic resources and inferred subeconomic resources.—Tonnage estimates for these classes of coal are determined by summing the estimates for measured, indicated, and inferred resources that do not meet the criteria for assignment to the reserve base or inferred reserve base because they are too thin to mine, are too deeply buried to mine, or are those parts of the reserve base or inferred reserve base that have been or will be lost-in-mining but whose attributes indicate future recovery may become feasible. Included are all measured, indicated, and inferred reliability categories of bituminous coal and anthracite beds 14 to 28 inches (35 to 70 cm) thick, all subbituminous coal beds 30 to 60 inches (75 to 150 cm) thick that are less than 1,000 feet (300 m) below the surface, and all lignite beds 30 to 60 inches (75 to 150 cm) thick that are less than 500 feet (<150 m) below the surface, unless the coal in these beds will be recovered in the process of extracting coal from thicker beds. Also included are all beds of bituminous coal and anthracite 14 inches (35 cm) or more thick and beds of subbituminous coal 30 inches (75 cm) or more thick that occur at depths between 1,000 and 6,000 feet (300 and 1,800 m) and lignite beds 30 inches (75 cm) or more thick and more than 500 feet (>150 m) below the surface.

thickness of coal for resource calculations.—The thickness of coal used for resource calculations is the net thickness of coal in a bed excluding all partings more than 3/8 inch (>1 cm) thick. Beds and parts of beds made up of alternating layers of thin coal and partings are omitted from calculations if the partings comprise more than one-half of the total thickness. Also, benches of anthracite and bituminous coal less than 14 inches (35 cm) thick and benches of subbituminous coal and lignite less than 30 inches (75 cm) thick are omitted from calculations if they lie above or below partings that may deter their mining. Coal and coaly material containing more than 33 percent ash is excluded from resource and reserve estimates unless the ash is largely in associated partings so that the coal is cleanable to less than 33 percent ash. (See **parting**, p. 15, and specific instruction No. 13, p. 36.)

undiscovered resources.—Tonnage estimates for this category of resources are based (1) on knowledge of the geologic character, habit, and pattern of a coal bed or coal zone in an area or region or (2) on speculative geologic data. Estimates are made by summing the tonnage estimates for coal assigned to the hypothetical and speculative resources reliability categories. Included are hypothetical and speculative resources of bituminous coal and anthracite in beds 14 inches (35 cm) or more

thick and hypothetical and speculative resources of subbituminous coal and lignite in beds 30 inches (75 cm) or more thick presumed to occur in mapped areas and in unmapped or unexplored areas to depths of 6,000 feet (1,800 m).

GUIDELINES FOR ESTIMATING COAL RESOURCES

These guidelines were prepared so that coal-resource workers will have logical and uniform procedures to follow. They combine the best features of the procedures used in preparing many previously published estimates of State and national coal resources with additions and modifications from numerous conferences with experienced coal resource estimators.

These guidelines are aimed at producing a uniformity of procedures so that coal-resource estimates prepared by various individuals and groups can be compared and (or) combined into meaningful totals for a quadrangle, township and range, coal field, basin, region, province, county, state, nation, continent, and (or) the world.

Some statements in the guidelines obviously are not rigidly applicable to all coal beds or coal-bearing areas. Where such shortcomings are perceived, a logical procedure is to develop new guidelines to effect appropriate changes in methodology so that they can be studied, criticized, and accepted or rejected by others.

The following statements are to be strictly adhered to by all coal resource specialists in the U.S. Geological Survey: *(1) All tables of coal resource or reserve estimates must contain a date and appropriate authorship information; and (2) each table of coal resource or reserve estimates must show where supporting basic data were located at the time of estimation.*

GENERAL GUIDELINES FOR CLASSIFICATION OF COAL RESOURCES

These general guidelines are required for uniform classification and reporting of coal into the different resource categories. They are modeled after the guidelines in Circular 831 (U.S. Geological Survey, 1980, p. 3–4) for all minerals.

1. All naturally occurring concentrations of coal can be distributed into one or more of the classification categories.
2. Where the term "reserves" is used without a modifying adjective, for example, marginal, indicated, restricted, low-sulfur, or inferred, it is to be considered synonomous with the demonstrated-economic category.
3. Quantities and qualities of coal may be expressed in a variety of terms and units to suit different purposes but must be clearly stated and defined.
4. A reserve base is a resource category delineated only by physical and chemical criteria. A major purpose for the recognition and discrimination of a reserve base is to aid in long-range public and commercial planning. A reserve base estimate for specific rank, thicknesses of coal and overburden, quality, usage, geologic formation, age, depositional environment, and many other factors can be specified for any given deposit or area, or for the Nation. The position of the lower boundary of a reserve base is intended to extend into the subeconomic category. The intention of this extension is to define quantities of in-place material, parts of which may become economic depending on the extraction plan finally utilized. As a result of any given extraction plan, the reserve base can be subdivided into component parts—reserves, marginal reserves, and a remnant of subeconomic resources. For the purpose of Federal (USGS) assessment, criteria for the reserve base are listed on page 29 of this report.
5. Undiscovered resources should be subdivided in accordance with the definitions of hypothetical and speculative resources or they may be subdivided in terms of relative probability of occurrence (see figs. 1 and 2).
6. Inferred reserves and the inferred reserve base represent postulated extensions of reserves and the reserve base. They are identified resources but are quantified with a relatively low degree of certainty. Postulated quantities of resources based on geologic inference alone should be assigned to the undiscovered categories.
7. Locally, limited quantities of coal may be produced from beds that are of insufficient thickness or are too deeply buried to be classified as reserves. This situation arises when production facilities are already established or when favorable local circumstances, such as particular coal qualities or removal of overburden for other purposes, make it possible to produce coal that otherwise could not be extracted profitably. Where such production is occurring, the quantity of in-place coal (including coal for in situ gasification) shall be included in a reserve base and the quantity that is potentially producible shall be documented as reserves. The profitable production of such coal, however, should not be used as a rationale to assign a reserves classification to coal in other areas having similar overburden, thickness of coal, and qualities.
8. Coal resources classified as reserves must be considered as economically producible at the time of

classification. Conversely, coal not currently producible at a profit cannot be classified as reserves. However, there are situations in which mining plans are being made, lands are being acquired, or mines and plants are being constructed to produce coal that does not meet economic criteria for reserve classification under current costs and prices but that would do so under reasonable future projections and expectations. The marginal reserve category applies to such situations. When economic production appears certain, coal classified as marginal reserves will be reclassified as reserves. Marginal reserves also may include any other coal whose economic producibility borders on being profitable.

9. Tonnage of coal that is too impure, too thin, too deep, or for other reasons not considered to be potentially economic may be estimated, but is not to be classified as a resource. These tonnages may be classified in the box labeled "other occurrences" in figures 1, 2, and 3.
10. Rank classes of coal, for example, bituminous coal as distinct from lignite, should be separately quantified.
11. The amount of cumulative production is not a part of the remaining coal resources. However, an understanding of what has been produced in the past is important to resource understanding, both in terms of the amount of production and the amount of coal remaining in place. Separate accounting for cumulative production should be made for each report area, county, State, and the Nation.
12. By-passed coal in large blocks left in the ground during mining, or planned to be left in the ground during current or future extraction, should be recorded in an appropriate resource category depending upon its economic recovery potential. Coal lost-in-mining should also be recorded in an appropriate resource category if there is a potential for further recovery.
13. In classifying reserves and resources it may be necessary to recognize locally that some coal deposits derive their economic viability from coproduct or byproduct relationships with other commodities.
14. Factors other than economic and geologic considerations, including legal, regulatory, environmental, and political concerns, may restrict or prohibit the utilization of all or part of a coal deposit. Reserve and resource quantities known to be restricted should be recorded as such in an appropriate category.
15. This classification system allows for the presentation of more subdivisions than will commonly be reported or for which data are available. Where appropriate, subdivisions may be aggregated or omitted.
16. Data supporting resource estimates are to be documented and preserved.

SPECIFIC INSTRUCTIONS

1. RANK OF COAL

Where coal of more than one rank class or rank group is covered by an individual report, the resource data shall be reported separately for each major rank class and when possible for each rank group listed below:

Class	*Rank group*	*Abbreviation*
Anthracite	Meta-anthracite	ma
Do	Anthracite	an
Do	Semianthracite	sa
Bituminous coal	Low-volatile bituminous coal	lvb
Do	Medium-volatile bituminous coal	mvb
Do	High-volatile A bituminous coal	hvAb
Do	High-volatile B bituminous coal	hvBb
Do	High-volatile C bituminous coal	hvCb
Subbituminous coal	Subbituminous A coal	subA
Do	Subbituminous B coal	subB
Do	Subbituminous C coal	subC
Lignite	Lignite A	ligA
Do	Lignite B	ligB

Abbreviations can be used wherever appropriate in reports and tables.

2. OVERBURDEN

Tonnage estimates shall be reported according to thickness of overburden:

Mandatory underground mining categories:	*Mandatory and optional surface mining categories*[1]*:*
0 to 500 feet (0 to 150 m)	0 to 500 feet (0 to 150 m) mandatory use
500 to 1,000 feet (150 to 300 m)	0 to 100 feet (0 to 30 m) optional use
1,000 to 2,000 feet (300 to 600 m)	100 to 200 feet (30 to 60 m) optional use
2,000 to 3,000 feet (600 to 900 m)	0 to 200 feet (0 to 60 m) optional use
3,000 to 6,000 feet (900 to 1,800 m)	200 to 500 feet (60 to 150 m) optional use
Optional other occurrence category:	
>6,000 feet (>1,800 m)	

[1]Use of optional surface mining categories requires the complete coverage of the 0–500 feet (0–150 m) category. Other categories may be used if they are in increments of 100 feet (30 m) and do not exceed 500 feet (150 m).

Resources of currently and potentially strippable and underground minable coal beds and coal zones shall be computed for the 0–500 feet (0–150 m) overburden category. Use of the surface mining optional categories allows tonnage estimates to be related to overburden. When optional categories are used, the sum of their tonnage estimates must be equal to the tonnage estimate for the 0–500 feet (0–150 m) category.

In addition, other criteria such as the ratio of overburden to coal thickness or the ratio of cubic yards of overburden to tonnage of coal may be used to outline and evaluate strippable coal deposits. Such departures from the standard categories and criteria are advisable only where there is adequate data.

3. THICKNESS OF COAL CATEGORIES

Tonnage estimates shall be reported by rank and thickness of coal:

Anthracite and bituminous coal	*Subbituminous coal and lignite*
14 to 28 inches (35 to 70 cm)[1]	2.5 to 5 feet (75 to 150 cm)[1]
28 to 42 inches (70 to 105 cm)	5 to 10 feet (150 to 300 cm)
42 to 84 inches (105 to 210 cm)	10 to 20 feet (300 to 600 cm)
84 to 168 inches (210 to 420 cm)	20 to 40 feet (600 to 1,200 cm)
168 inches or thicker (420 cm +)	40 feet or thicker (1,200 cm +)

[1]Centimeter thicknesses may be reported in meters.

4. SIZE OF UNIT AREA

For future planning by Federal and State governments, industry, and the public, coal resources such as identified resources, reserve base, and reserves, are to be estimated for relatively small areas. Unit areas the size of townships, 7.5-minute quadrangles, and 15-minute quadrangles generally are satisfactory. For specific purposes such as tract assessment, evaluation, and management, however, it may be desirable and (or) necessary to report estimates for areas as small as an individual land section, or smaller.

In addition, there are many requirements for estimating the remaining tonnages and type of coal for each coal-bearing county, State, and the Nation. Although tonnage estimates for most currently known coal-bearing counties and States exist, many are inadequate and out of date. Numerous requests for information emphasize the need for modern reliable county and State estimates. Such modern estimates are to be prepared as information becomes available and can be assembled. The unit area for such re-evaluations is logically a completed county, the smallest unit universally employed by State and National agencies. Therefore, all resource estimates regardless of size of area (except for State and national estimates) must be reported by the county in which they occur.

5. MAJOR CATEGORIES OF RESOURCES

Estimates of the total coal tonnages in the following resource categories are required, where data are available, for adequate inventorying of county, State, and national coal resources: measured, indicated, inferred, and hypothetical resources; reserve base and inferred reserve base; and original resources and remaining resources. Additional divisions of total resource estimates are not required but are desirable to document more thoroughly the quantities of coal available for particular uses.

6. COAL BED MAPS

A map of each coal bed or coal zone known to contain coal resources must be prepared to document the estimate for coal resources. A coal bed map will show (1) the trace of a bed's outcrop; (2) all points where the thickness of coal was measured at outcrops and other surface exposures; (3) all wells, drill holes, and subsurface points where the thickness of coal was measured; (4) county, State, and national boundaries; (5) land lines (townships and ranges) and latitude and longitude coordinates; (6) boundaries of Federal and State Parks, forests, wildlife refuges, grasslands, military bases, and areas known to be environmentally or legally restricted from mining; (7) reliability categories; (8) isopachs of thicknesses of coal and overburden; (9) structure contours; (10) areas where coal is absent because of erosion or nondeposition; (11) structural features affecting coal, such as fold axes and traces of faults; and (12) boundaries of prior surface and subsurface mining. Information derived from proprietary data can be deleted where required by the author in preparing a bed map for publication. Such proprietary information may include, for example, points of thicknesses of coal beds and overburden, drill-hole locations, mine boundaries, and other data furnished by mining companies or land proprietors. Coal beds may be so numerous in some areas that only selected bed maps of the major deposits would be published, even though bed maps of all coal beds would be prepared in order to estimate the resources.

Figures 9 through 23 show how to prepare parts of a coal bed map. Tables 4 through 7 show listings of areas of reliability by thicknesses of coal and overburden categories derived from figures 9 through 23. The areal

interrelations of data depicted on a coal bed map define a series of areas, each of which represent a separate coal resource category. The areal extent, average thickness of coal, and the depth, rank, and weight of coal per unit-volume in each area must be determined in order to estimate the tonnages of coal underlying each area.

7. THICKNESS OF COAL MEASUREMENTS

The stratigraphic thickness of coal is measured at outcrops, in trenches and prospect pits, at mine faces either underground or in surface pits, and in drill holes by direct measurement or geophysical logging. (See "Geophysical Logs* * *," p.46.) *Measurements may be made in inches or in feet and inches, in feet and tenths of feet, or in meters and centimeters*. Partings in a coal bed greater than 3/8 inch (1 cm) should be excluded from the thickness measurements of a coal bed when estimating coal resources (see ***thickness of coal for resource calculations***, p. 31, and specific instruction No. 3, p. 34) but should be recorded as stratigraphic information. *Field measurements of the thicknesses of coal beds should be made to the nearest 1 inch, tenth of a foot, or metric equivalent. Thicknesses determined from core and drill-hole logs and from geophysical logs should be reported to the smallest practical unit of measurement. The weighted average thickness of a coal bed based on field measurements in an area should be reported to the nearest inch, tenth of a foot, or metric equivalent*. An average thickness should be determined by using all measurements of coal, by the thickness gradients between measurements, and by isopaching. The thickness of coal at specific points should be recorded on coal bed maps, and then the bed should be isopached using the points of measurements and gradients between the points. An isopach should be drawn along each of the standard coal thickness category limits pertinent to the rank and thickness of coal in the area to be estimated. The weighted average thickness of an area of coal is calculated by estimating the size of each isopach unit according to the percent or proportion of the area covered by the unit. Where mining has been extensive, the thickness of coal in unmined areas can be extrapolated from data on thicknesses of coal obtained from mine maps and from adjacent mines.

8. DISTRIBUTION OF COAL BED THICKNESS MEASUREMENTS

The distribution of data points is exceedingly important in the estimation of coal resources because distribution (including spacing) is universally considered as the ultimate control governing the reliability, accuracy, and precision of any estimation. In most areas the coal resource worker must rely on existing outcrops, trenches, prospect holes, mine workings, and drill-hole data. If drilling is possible, a drilling pattern should be established, on the basis of geologic knowledge, to supplement the existing data so as to raise the assignment of coal resources to a higher degree of reliability.

9. MEASUREMENT OF AREAS

Coal-bearing areas, as determined from coal bed maps (see figs. 9–23) are to be measured to a precision of 2 percent or less. Such determinations may be made with a planimeter, with graph paper, with equally spaced dots, or with a computer. The most common instrument used for area determinations is the polar planimeter. In recent years the digital electronic planimeter has become increasingly popular. Prior to determining areas with a planimeter, a planimeter factor for acres or hectares, which depends upon the scale of the map used, must be ascertained. This is done according to instructions that accompany the planimeter. A similar factor must be determined if the graph paper technique of determining acreages is employed. After either factor is ascertained, the user is prepared to start measuring areas on the map and to convert the measurements using the appropriate planimeter or graph paper factor into acres or hectares.

On many 7.5-minute quadrangles, several dozen to several hundred areas must be measured that are based on the many parameters into which coal-bearing areas can be categorized. These parameters may include thicknesses of coal and overburden; distance from points of coal thickness measurements (reliability categories); quality; physical characteristics; rank, land ownership by Federal, State, Indian, and local governments, companies, individuals, and other nations; county, State, and townships and ranges of the land classification system; quadrangle, coal field, basin, region, and province; legally and environmentally restricted areas, and others as desired.

As the areas are measured, mean results ascertained by averaging the planimeter or graph paper readings are recorded so that each area's acreage can be computed.

A planimeter is accurate in measuring map areas ranging from several square inches to 20–30 square inches. Generally, planimetric measurements are repeated several times and then averaged. However, if readings are in disagreement by more than 2 percent, they should be repeated until an agreement of 2 percent, or less, is achieved. Map areas of less than 1 square inch

commonly are not as precisely measureable with a planimeter as are larger map areas and must be remeasured and the planimeter vernier read many times to obtain an agreement within a 2-percent error. Repetition of planimetric measurements with only two vernier readings, one at the beginning and one at the end, can be accomplished by continuously tracing the borders of the area being measured a predetermined number of times in a manner similar to the repetitive turning of angles with a transit by a surveyor. The difference between the two readings should be divided by the number of times the borders are traced; the answer multiplied by the planimeter factor is the size of the area. This repetitive measurement of an area is a good method of obtaining precise planimetric readings.

10. WEIGHT OF COAL PER UNIT VOLUME

A tonnage estimate for any coal deposit can be made if the thickness of coal, areal extent, and weight of coal per unit volume are known. The weight of coal per unit volume (density) or specific gravity varies with rank, ash content, and the amount of each macerals group (such as vitrinite, inertinite, and exinite) in the coal. Ideally the density of coal in a deposit should be determined from numerous specific gravity determinations on unbroken coal, but there are rarely sufficient determinations to characterize a deposit. Therefore, it is recommended that tonnage calculations be based either on the average specific gravity or the average weight of unbroken coal per unit volume of the different ranks shown in table 2.

11. CALCULATION OF COAL RESOURCES

After the area underlain by coal, the average thickness of coal, and the weight of coal per unit volume for each category shown on a coal bed map have been determined, the tonnage can be estimated. The tonnage is estimated by the following formula:

$A \times B \times C$ = tonnage of coal where

A = weighted average thickness of coal in inches, feet, centimeters, or meters,

B = weight of coal per appropriate unit volume in short or metric tons, and

C = area underlain by coal in acres or hectares.

12. ROUNDING OF TONNAGE ESTIMATES

The rounding of tonnage figures shall be done only after all calculations have been completed using data for areas (acres or hectares), coal thicknesses, and weight of coal per unit volume and summed for each coal category. The tonnage estimates for each coal category are then rounded to significant numbers so as to not eliminate tonnage estimates for small areas of measured and indicated coal. For example, the tonnage estimates for small areas such as A, B, C, F, G, H, K, M, O, P, Q, and R in figure 17 and A, B, C, D, E, F, G, H, L, Q, W, Y, AA, HH, and OO in figure 19 are not rounded out of the totals and are included in the summing of the total coal resources for all areas in figures 17 and 19. After summing, the resultant total coal resources estimates for a whole map area (a quadrangle, county, or basin) are not rounded because their component parts have been rounded.

13. ESTIMATION OF RESOURCES IN THE VICINITY OF WHERE A COAL BED BIFURCATES INTO TWO OR MORE TONGUES

Resource estimation is difficult in those localities where a coal bed bifurcates or splits into tongues, each of which exceeds the minimum thickness for resource estimation. The difficulty is caused by the necessity to delineate a boundary between the area where the resources of the main coal bed are estimated and the areas where the resources of the tongues are individually estimated.

As stated in the glossary, a **parting** is "a layer or stratum of non-coal material in a coal bed which does not exceed the thickness of coal in either the underlying or overlying benches" of coal. Where the non-coal material exceeds the thickness of either the underlying or overlying parts of the coal bed, the coal bed is considered for the purpose of resource estimation to have split into two coal beds (each of which is depositionally a tongue from a thicker main coal bed).

In estimating resources in such a geologic situation, it is necessary to delineate on a coal bed map the areas where resources will be separately calculated; to do so, a line is used to connect all points where one of the tongues becomes thinner than the intervening parting. It is also necessary to locate on the coal bed map all points where the thickness of the main coal bed and the tongues were measured. Measured, indicated, and inferred reliability circles should be drawn on the bed map from each point of thickness of coal measurement on the main bed and the tongues. The circles should be drawn, according to the appropriate distance for each reliability category, across the boundary line for resource estimation. After the circles are drawn, the thickness variations of the main coal bed and each tongue (bed) are to be isopached separately. Tonnage estimates should then be

calculated for each tongue (bed) and the main bed using procedures outlined elsewhere in this report for separate coal beds.

ESTIMATION OF HYPOTHETICAL RESOURCES

The estimation of hypothetical coal resources in areas where geologic, thickness, rank, and areal size data are sparse or absent is necessary to promote exploration for poorly known and undiscovered coal areas. Currently about 2.24 trillion short tons of the Nation's 3.68 trillion tons of remaining coal resource inventory are classified as undiscovered (hypothetical) (Averitt, 1975). Much additional unknown coal may be concealed in the central parts of basins and is not as yet included in the Nation's coal inventory. This additional unknown coal must be identified, as must the 2.24 trillion tons currently remaining in the inventory, because knowledge of the quantity, quality, and rank of the unknown and hypothetical coal could influence the Nation's energy usage plans. Therefore, a question commonly asked by government and industry estimators responsible for inventorying coal resources is: How do you estimate resources where there are no nearby thickness, depth, and rank data? Another way of stating this question is: How do you estimate the resources of central parts of poorly explored or unexplored basins?

The problem of estimating hypothetical resources in the central parts of basins and elsewhere has been approached by (1) not attempting to calculate them; (2) assuming that the centers of the basins or coal-bearing areas where control is lacking are barren of coal; (3) assuming that the better known marginal areas of coal-bearing basins are representative of the average quantity of coal per square mile in the central parts of the basins; (4) assuming an average thickness of coal and applying this factor to the volume of coal-bearing rocks in an area; and (5) making an outright guess. None of these solutions are satisfactory. A sixth solution has been to extrapolate measurement data from surrounding areas into the unknown area. This approach is better than the others but commonly is inadequate because it does not consider geologic factors that would control unsystematic distribution of coal in an unknown area.

The following discussion describes two methods, based on geologic principles, for estimating hypothetical resources. Both are acceptable if the supporting basic geologic and measurement data are documented and presented for evaluation. These alternative approaches can be termed the "extrapolated bed map method" and the "extrapolated coal zone method." Both methods are based on the extrapolation of geologic knowledge and measurement data into an area of unknown coal resources. In some problem areas, a mix of the two methods may be desirable.

Much of the data called for in the descriptions of the extrapolated bed map and extrapolated coal zone methods will not be available in many areas where hypothetical resources must be estimated. The descriptions of the methods are written for the ideal amount of control adjacent to an unknown area; thus, the methods will have to be modified on the basis of the type, availability, and amount of control data.

EXTRAPOLATED BED MAP METHOD

Step 1.—Assemble all available geologic data in the areas adjacent to the unknown area for the coal bed whose resources are to be estimated.

Step 2.—Assemble and plot on a base map all pertinent data on thicknesses of coal and overburden, quality of coal, reports of coal in drill holes and wells, and rank of coal.

Step 3.—Analyze all data collected in steps 1 and 2 to ascertain trends of coal deposition by (a) constructing isopach maps of the coal bed in known areas; (b) constructing isopleth maps of heat values, ash contents, and contents of trace elements that may be related to sources of sediment; and (c) identifying trends of persistent thick or thin coal, or other parameters of coal.

Step 4.—Identify depositional and erosional trends and features in the known areas of rocks adjacent to the coal bed and in the coal bed itself that may indicate ancestorial through-flowing rivers in swamps, coastal environments, unconformities, directions of delta building, paleogeomorphic locations of swamps on a coastal plain or delta, and directions and distances to sediment sources. Plot all pertinent data on a map.

Step 5.—Extend stratigraphy from known areas into and across the unknown area by utilizing all surface and subsurface information. Collect surface stratigraphic data and existing petroleum and water well information. Evaluate and analyze all data and determine best correlations so that coal bed extensions and correlations can be made. Determine from available data probable geologic model of deposition. Plot all data on the map of step 4.

Step 6.—Construct structure sections across the unknown area so that changes in the thickness of overburden and rank of the coal bed can be considered and (or) postulated.

Step 7.—Construct a structure contour map of the coal bed in the unknown area.

Step 8.—Combine all pertinent data from steps 2, 3, 4, 5, and 7 onto a single coal bed map.

Step 9.—Fill in the unknown area by projecting pertinent coal and other data across or through the unknown area. This projection should include isopachs for thicknesses of coal and overburden, isopleths for rank and (or) heat values, predicted erosional channels cutting through the coal, and other stratigraphic, depositional, or structural features affecting the coal bed.

Step 10.—Place land lines and boundaries of political subdivisions on the map.

Step 11.—Define areas of hypothetical coal by plotting the outer limits of inferred coal as determined from points of thickness control in the known areas. Determine acreages of hypothetical coal for the following resource categories: thicknesses of coal and overburden; rank; quadrangle; townships and ranges; counties; and State.

Step 12.—Determine the average coal bed thickness for each acreage unit in each category.

Step 13.—Calculate and sum estimated tonnages for each category, round estimated tonnages to significant figures as per specific instruction No. 12, p. 36, and sum into a final hypothetical tonnage. These estimated tonnages and the total summed tonnage probably represent the best information that can be estimated for a bed that extends from a known area into an unknown area where control points are absent or sparse.

EXTRAPOLATED COAL ZONE METHOD

If the procedure for an extrapolated bed map analysis of hypothetical coal resources is impractical because of time limitations or sparsity of data it is suggested that the approach to estimating hypothetical resources be by an extrapolated coal zone method.

Step 1.—Determine if a coal zone exists by analyzing the available data.

Step 2.—Assemble and plot on a base map all available geologic data in areas adjacent to the unknown area.

Step 3.—Construct an isopach map of the cummulative thicknesses of all coal beds in the coal zone (less partings) that exceed 14 inches for anthracite and bituminous coal beds and 30 inches for lignite and subbituminous coal beds in known areas.

Step 4.—Identify trends and geologic features in the rocks of the coal zone in the known area that may indicate persistent ancient through-going rivers, coastal environments, unconformities, directions of sediment transport, intertonguing sediments and coal beds, regressions and transgressions, and so on. Plot pertinent data on a map.

Step 5.—Extend stratigraphy of the coal zone and related rocks into and across the unknown area on the map of step 4 by utilizing all surface and subsurface data. Determine geologic model of deposition of the coal zone. Construct stratigraphic diagram of the coal zone and fit diagrammatic data to the map.

Step 6.—Construct structure sections across the unknown area so that thickness of overburden and rank changes of coal zone can be considered and (or) postulated.

Step 7.—Construct a structure contour map of the coal zone in the unknown area.

Step 8.—Combine all pertinent data from steps 2, 3, 4, 5, and 7 onto a single coal zone map.

Step 9.—Fill in unknown area by projecting pertinent coal zone and other data across or through unknown area.

Step 10.—Place land lines and boundaries of political subdivisions on map.

Step 11.—Define areas of hypothetical coal by plotting an outer limit of inferred coal as determined from points of thickness control in the known areas. Determine acreages of hypothetical coal for the following categories: thicknesses of overburden, cummulative thicknesses of coal, rank, quadrangle, townships and ranges, counties, and State.

Step 12.—Calculate and sum tonnages for each category after determining a cummulative thickness of coal for each acreage unit in each category and calculating tonnage. Round tonnages to significant figures as per specific instruction No. 12, p. 36, and sum into a total hypothetical tonnage amount.

The extrapolated coal zone solution for hypothetical coal eliminates the estimation of tonnages for many individual beds and, in the view of some workers, provides a more valid estimate than the bed-by-bed approach. Despite this view, the bed-by-bed method is herein recommended for use where practicable and (or) feasible.

EXAMPLES ILLUSTRATING THE BASIC GEOMETRIC PRINCIPLES OF CONSTRUCTING COAL RESOURCE BED MAPS

Coal resource estimation systems on a worldwide basis generally lack illustrations amplifying written instructions as to how to calculate coal resources.